1.1   Plots, Sketches, and Graphs

Plotting, sketching, graphing are they different? Bananas, oranges, and coconuts are all edible fruits. Yet they all have a sharp contrast in taste and texture. But they all must be peeled to be eaten. Clearly there are similarities and differences in bananas, oranges, and coconuts as there are in plotting, sketching, and graphing.

The common thread in plotting, sketching, and graphing is that they are all forms of communication. If each plot, sketch or graph could talk it would be saying something important about the relationship of two or more parameters. It is your job to be able to construct plots, sketches and graphs using good standard engineering conventions so that they can effectively communicate information.

Plotting and graphing are nearly identical. Usually you plot points of data from an experiment and graph analytical functions like y = mx + b. Both require you to have exact coordinates and visually represent the relationships in perfect proportions on the paper. Both are time consuming and require a fair amount of skill. Both are made more easily with the help of a computer and typically a spreadsheet program to facilitate the procedure.

Plots and graphs should be done on graph paper (or with a computer) that has major and minor axes in both the horizontal and vertical directions. The distance between each major axes should be 1, 2 or 5 times 10 raised to some power. For example 0.01, 0.1, 1 10, and 100 would all be considered acceptable as distances between major axes. This makes it easier for others to read and interpret as well as for you to construct. You must choose the correct number of minor axes so they will be evenly spaced at convenient numbers between the major axes. For example if my major axes are 0.5 units apart then choosing 4 minor axes will result in a minor falling at 0.1, 0.2, 0.3, and 0.4 units. This would be very nice if you needed to find a point between 0 and 0.5.

Plotting and graphing usually reveal a relationship that wasn't all together clear before representation in this way. Some fundamental truth is brought to the surface that was hidden before. Trends are more easily seen and visually quantified.

Sketches on the other hand are quick and easy pictures of plots and graphs. The idea is not to plot out exact points on graph paper but to quickly label each axes and show the shape of the curve by "free handing" it. With sketches you already know the relationships and you are merely trying to convey these ideas to someone else.

When sketching always show and label all significant points on each curve such as maximums, minimums, inflections, asymptotes, etc. If there is more than one curve on a single sketch than provide the reader a way to separate each by using different line types or colors along with a "key" or "legend box" labeling each.

Common to all of your plots, sketches, and graphs will be the format in which you label your axis. **Each axes should always include words to describe the parameter, a symbol that is commonly used for that parameter, and the units commonly used by that parameter.** Only then will you be effectively communicating to others. (And in the future, yourself, when you go back and re-read your notes.)

When faced with a blank piece of paper and the task of having to sketch out a relationship you should always begin by labeling the axes with words, symbols, and units. Next think about what you are about to sketch and recall the physical basis of the relationship between your axes. Then you should mark or label any significant points such as beginnings, endings, maximums, minimum, asymptotes, inflections, etc. Finally draw the shape of the "curve". If the "curve" is a straight line (we say it's linear) use a straight edge to draw it.

Constructing sketches in any other order will result in having to memorize the shape instead of constructing it from a combination of logic and physical understanding. The saddest comment on a student course critique is, "the course is just memorizing information." If you feel this way then you are thinking entirely in the wrong way. Engineers do not think this way. The course will be very hard to master from the wrong perspective. Begin today understanding the difference between memorization and conceptualization.

When you physically understand the relationship between parameters the graph will practically sketch itself. Labeling each axis with words, symbols, and units is the first step in this process - use it!

The golden rule about plots, graphs, sketches, charts, tables, and figures is that they should stand alone. In other words, if someone was to read just the plot, graph, sketch, chart, table or figure, they should be able to understand all the information completely without reading any other source.

1.2   Dependent and Independent Variables and Their Relationships

In general, the horizontal axis is referred to as the X-axis and the vertical axis is the Y-axis. Conventionally the X-axis is used for the independent variable and the Y-axis is the dependent variable. The "dependent" variables value will depend on the value of the "independent" variable. An example of an independent variable is time. Time marches along quite independently of other physical processes. There can be, and often is, more than one independent variable in a mathematical relationship.

The concept of a dependent and independent variable(s) are fundamental but extremely important. The relationship of the dependent variable to the independent variable(s) is what is sought in science and engineering. Sometimes you will see the following notation in math and science that lets you know what the dependent variable actually depends on or is a function of.

$$Parameter\ Name\ =\ f(independant\ variable\ 1,\ independant\ variable\ 2,\ etc)$$

Where "Parameter name" is any dependent variable being studied. It is read "Parameter name is a function of independent variable 1, 2, etc". Use this notation whenever you want to say , "is or as a function of". If you wanted to state that hydrostatic pressure is a function of depth you could write.

$$P\ =\ f(depth) \qquad\qquad where\ P\ is\ the\ hydrostatic\ pressure$$

There are several ways to develop the relationship between the dependent and independent variable(s). One is by doing an experiment and collecting raw data. The data is plotted as discrete points on some independent axis. Once plotted, a smooth curve is faired through the data. Never just connect the points like a "connect the dots" picture in a children's game book. Nature doesn't behave this way. The true curve is smooth and is assumed to be "centered" about the data that is taken. Fairing or interpolating a curve through experimental data is an art that requires skill and practice. Computers with the appropriate software can make this a relatively simple task and arrive at an analytical equation for the smooth curve based on minimizing the sum of the squared distances from the smooth curve to all the data points. This approach is referred to as empirically finding the relationship through regression.

Besides empirical curve fitting experimental data to arrive at a relationship a scientist or engineer may go about finding a relationship from a conservation law, theoretical principle or postulate. As a simple example, the conservation of mass is often used to write a mass balance to describe a process in which mass is entering and leaving a control volume.

There are also semi-empirical equations that are a combination of theory and data fitting. This is the way most of engineering works. Important parameters are identified in the physical process and then an exact analytical expression is developed with the help of experimental data. If you are the first person to do this for some niche in science you could have a "constant" named after you!

In lab you will be plotting data by hand and fairing smooth curves through your data points to approximate the true curve. You can use some combination of drawing tools to accomplish this including a straight edge, a set of french curves, or a plastic flexible curve. All tools should be made of transparent materials to allow you to center your curve through the data - thus obtaining the best fit.

1.3   The Region Under the Curve and the Instantaneous Slope at a Point on the Curve

As discussed previously the shape of the curve reveals information about the relationship between the dependent and independent variables. Additionally, more information can be obtained by understanding what the region under the curve and the slope of the curve is telling you.

The region under the curve is often called the "area" under the curve.   The word "area" is misleading in one sense because this "area" can physically represent any quantity or none at all. Don't be confused or mislead into thinking that the area under the curve always represents area as in square feet, it may not.

When you integrate (a calculus term for sum up) a function (a curve) over some distance on the independent axis (X-axis) you are calculating the region or "area" under the curve. To see if this "area" means something physically, investigate the units of the "area".

To find the units on the "area" take the units on the Y-axis and multiply them by the units on the X-axis. This product will be the new units of the "area" under the curve. If the area under the curve has a physical meaning you will often discover it this way. Integration of a function yields a new independent relationship that didn't exist before.

The slope of the curve is the change in the dependent variable over some change in the independent variable. We say it's the "rise over the run" in short. This is called a derivative in calculus. The derivative of a function yields a new independent relationship that wasn't known before.

The slope of the curve at any point is called the instantaneous slope since it is the value at a single instance on the curve. Strict mathematicians might only use the word "instantaneous" when the independent variable is time, as in at that instance of time, but engineers interpret the word in a more broad usage. To determine the physical meaning of the slope (if there is one) take the units on the Y-axis and divide them by the units on the X-axis (Rise over Run). The new units of the slope will often give you the physical meaning.

1.4   Unit Systems

There are three commonly used unit systems in engineering. You have probably used them all at
one time or another. Different disciplines in science prefer using different systems by convention.
For example, physicists love to use the metric system (Known as the International System of Units
(SI) from the French name, Le Système International d' Units), Naval Architects still use the
British "pound - slug" system, and Thermodynamicists have a penchant for the English "pound
force - pound mass" system.

One tries to use the units commonly used in the discipline you are studying. While it is not
technically wrong to measure a quantity in units of any system it is considered extremely bad
practice to do so. You must use the British "pound - slug" system in this class exclusively.

The following explanations of the three unit systems is not for the faint of heart. It is a
fundamentally important concept in science that will be laid out here for your educational
background.

The SI system and the English "pound - slug" system of units have their roots in Newton's second
law of motion: Force is equal to the time rate of change of momentum. In defining each term of
this law, a direct relationship has been established between the four basic physical quantities used
in mechanics: force, mass, length, and time. Through the arbitrary choice of fundamental
dimensions, some confusion has occurred in the use of the two English systems of units. Adoption
of the SI system of units as a world standard will overcome these difficulties.

The relationship between force and mass may be expressed by the following statement of
Newton's second law of motion:

$$\vec{F} = \frac{m \; \vec{a}}{g_c}$$

Equation 1.1

> where "g_c" is a conversion factor which is included to make the equation dimensionally
> consistent, "F" is the force "m" is the mass and "a" is the acceleration.

In the SI system, mass, length, and time are taken as basic units. The basic units are mass in
kilograms (kg), length in meters (m), and time in seconds (s). The corresponding derived unit of
force is the newton (N). One newton is defined to be the force required to accelerate a mass of
one kilogram at a rate of one meter per second squared (1 m/s^2). The conversion factor "g_c" is
then equal to one kilogram meter per newton - second squared (1 kg-m/N-s^2).

In the English "pound - slug" system, force, length, and time are taken as basic units. The basic units are force in pounds (lb), length in feet (ft), and time in seconds (s). The corresponding derived unit of mass is the slug (slug). One slug is defined to be the mass that will be accelerated at a rate of one foot per second squared (1 ft/s²) by one pound (lb). The conversion factor "g_c" is then a multiplying factor to convert slugs into (lb-s²/ft) , and its value is 1 (slug-ft/lb-s²).

Since the numerical value of "g_c" is equal to one for the SI and "pound - slug" system it is often left out of the Newton's second law out of laziness by scientists. Indeed many people use " F = ma " as if there were no "g_c" value.

In the British "pound force - pound mass" system, the concept of force or mass is not defined by Newton's second law, but is instead established as an independent quantity. Thus, for this system, unlike the other systems of units, the conversion factor "g_c" is not unity and the numerical value becomes necessary when using Newton's second law. The unit for force is defined in terms of an experimental procedure as follows. Let the standard pound mass (lb_m) be suspended in the earth's gravitational field at a location where the acceleration due to gravity is 32.1740 ft/s². The force with which the standard pound mass is attracted to the earth is defined as the unit for force and is termed a pound force (lb_f). In this system it is important to distinguish between a "pound mass" and a "pound force" and the term pound is never used alone. The magnitude and units of the conversion factor "g_c" can be determined from Newton's second law since we have independently defined the units for force, mass, length, and time.

$$\vec{F} = \frac{m \, \vec{a}}{g_c}$$

$$1 \; lb_f = \frac{1 \; lb_m \; 32.174 \; \frac{ft}{s^2}}{g_c} \qquad\qquad \text{Equation 1.2}$$

$$g_c = 32.174 \frac{lb_m \; ft}{lb_f \; s^2}$$

NB: The conversion factor "g_c" has both a numerical value and dimensions. For gravitational accelerations that are numerically close to "g_c" the pound force is approximately equal in magnitude to the pound mass. This is the reason that sometimes lay people drop the designation of force or mass after the word pound. This can lead to confusion and inconsistencies. When using this system be sure to always write the full name of pound force or pound mass.

In this class you will be using the British "pound - slug" system exclusively. Table 1.1 is a summary of these three systems.

System	Length	Time	Force	Mass	g_c
SI	meter (m)	second (s)	newton (N)	kilogram (kg)	1 $(kg\text{-}m/N\text{-}s^2)$
pound-slug [We use this one!]	**foot (ft)**	**second (s)**	**pound (lb)**	**slug $(lb\text{-}s^2/ft)$**	**1 $(slug\text{-}ft/lb\text{-}s^2)$**
pound-force pound- mass	foot (ft)	second (s)	pound force (lb_f)	pound mass (lb_m)	32.17 $(lb_m\text{-}ft/lb_f\text{-}s^2)$

Table 1.1- Comparisons of the Three Systems of Units.

1.4.1 Unit Analysis

Wouldn't it be nice if someone handed you a list of steps to go through for each problem you had to solve? Well the next best thing is dimensional analysis. Dimensional analysis is keeping track of the units in solving an engineering problem. More often than not, there is no formal equation to follow in a calculation. One simply thinks to themselves, "This is the value I have, this is the value I want, now how do I change from the units I have into the units I want?" This is like a having a road map to get to some place from where you currently stand.

To be able to do dimensional analysis you must know the units of each parameter and understand the relationships between fundamental dimensions and derived units.

When you are doing calculations or dimensional analysis it is helpful to use the "ruled lines method". (In high school it is called the "railroad track method".) This method is done by making horizontal and vertical guide lines for the multiplications and divisions in your calculations. Numbers and units are placed appropriately to segregate them into organized places. The following is an example of the ruled lines method.

Example of "Ruled Lines Method":

A student is asked to find the weight of a ship in tons given that the ship is floating in salt water with a submerged volume of the hull equal to 4000 cubic feet. The student knows about dimensional analysis, Archimedes principle, and the concept of static equilibrium. Here is the student's calculation showing the usage of the "ruled lines method".

$$\text{Tons} = \frac{4000 \text{ ft}^3 \quad | \quad 1.99 \text{ lb s}^2 \quad | \quad 32.17 \text{ ft} \quad | \quad 1 \text{ ton}}{| \quad \text{ft}^4 \quad | \quad s^2 \quad | \quad 2240 \text{ lb}}$$

Tons = 114.32 tons

NB: This example is only meant to show the ruled line method. The physical concepts used in this calculation are Archimedes principle and static equilibrium. You will learn these concepts very soon!

Notice how neat and organized this makes your calculation. This would be very easy for another engineer to understand and verify your work. **Please do all calculations in this course in this manner**. It is a wonderful engineering practice that effectively communicates your ideas. The ruled lines method also makes the dimensional analysis of the problem much easier.

Check your final answer for reasonability in magnitude and for proper units. You should have a "ball park" idea on the magnitude of the final answer. If you get an outrageous number, state, "this number is unreasonable," on your paper. Watch your units on your final answer. For example, if you are finding a <u>volume</u> but you end up with "pounds" you know you made a mistake. Units are a dead give away when it comes to finding mistakes in your calculations. They can save you many points on an exam. Analogy - If you are trying to find corruption in business follow the money. If you are trying to find errors in engineering follow the units!

1.5   Rules for Significant Figures

Numbers that are obtained from measurements contain a fixed number of reliable digits called significant figures. The number of significant figures in a number is equal to the number of digits known for sure, plus one that is uncertain. The number 13.56 has four significant figures as shown.

When combining several different measurements, the results must be combined through arithmetic calculations to arrive at some desired final answer. To have an idea of how reliable the calculated answer is we need to have a way of being sure the answer reflects the precision of the original measurements. Here are a few simple rules to follow.

For multiplication and division, the number of significant figures in the answer should not be greater than the number of significant figures in the least precise factor. For example, the answer in the following expression has only two significant figures because the least precise factor "0.64" only contains two.

$$\frac{3.14 \ \text{x} \ 2.751}{0.64} = 13.$$

For addition or subtraction, the answer should have the same number of decimal places as the quantity having the least number of decimal places. For example, the answer in the following expression has only one decimal place because "125.2" is the number with the least number of decimal places and it only contains one.

$$\begin{array}{r} 3.247 \\ 41.36 \\ + \quad 125.2 \\ \hline 169.8 \end{array}$$

Many people prefer to add the original numbers and then round the answer. If we enter the original numbers into a calculator, we obtain the sum "169.807". Rounding to the nearest tenth again gives the answer "169.8".

Not all numbers we use come from measurement. Sometimes in performing calculations, we use numbers that come from a direct count of objects or that result from definitions. Such numbers are called "exact numbers" and are considered to possess an infinite number of significant figures. An example is the number of inches in one foot. By definition, there are exactly 12 inches in 1 foot.

When using exact numbers in calculations, we can forget about them as far as significant figures are concerned. When you have mixed numbers from measurements with exact numbers you can determine the number of significant figures in the answer in the usual way, but take into account

only those numbers that arise from measurements.

For convenience in this course, you can assume all numbers are exact unless otherwise told. Give a reasonable number of decimal places in your answer and use some common sense. For example, if someone asked you how much you weigh you wouldn't say 150.5756789 pounds. As a general rule give at least 2 decimal places or as many as it takes to show your instructor your answer reflects you have done everything correctly. If your instructor is looking for a change in draft that is less than half a foot and you give your answer to the nearest foot then there is no way to see if your calculation is correct or not.

1.6   A Physics Review

It might well be argued that the basis of all engineering knowledge is founded in physics. Truly it is one of the most fundamental sciences. A short review of your physics knowledge will make learning Naval Engineering easier and more enjoyable.

When appropriate, concepts of Naval Engineering will be integrated with the physics, so read carefully. It is a good idea to always have a piece of paper and pen when reading or studying something technical. You should be writing out key words, definitions, sketches, pictures, tables, figures, example problems, etc. This is not a paper you are going to keep necessarily. This is a technique in learning that keeps you interactive. Studies have shown that you gain a deeper understanding when you do this and you retain the information in long term memory.

Reading something technical is not at all like reading a novel. In extreme cases a single page can take an hour or more to digest. Do it the same way you eat a 10 ounce steak, bite by bite, or in this case sentence by sentence! You must be well rested and in a quiet non- distracting environment to make the time you are studying effective. Analogy - When developing a relationship with a person it is the combination of time and quality of time that produces intimacy. Learning engineering concepts is no different. To internalize the concepts you must spend quality time with the information.

1.6.1   Scalars and Vectors

A scalar is a quantity that has only magnitude. Mass, speed, work, and energy are examples of a scalar quantities. Vectors have magnitude, direction, and obey the parallelogram law of addition. Vectors are represented in textbooks in bold typeface or as a symbol with a half or full arrow over the symbol.

Vectors can be resolved into scalar components in each principal dimension. For rectangular coordinates the 3 dimensions are the X, Y, and Z directions. Velocity, momentum, force, and acceleration are examples of vector quantities. Your equations must internally consistent with respect to vector notations.   Many students insert a vector arrow over a symbol when they shouldn't and forget to insert one when they should. Vector equations have special mathematical properties and are much more complex to deal with. Often a vector equation will be broken up into three scalar equations in each of the principal directions.

You will be drawing many pictures showing vectors in action. One of the more common vector pictures you will be drawing is that of the resultant weight and resultant buoyant force of a floating ship. The lines of action and point of application of these two vectors can explain most of the stability properties of a ship floating in the water.

The line of action of a vector is an imaginary line running coincident with the vector and extending on into infinity in both directions along the line. It is a useful concept in finding the perpendicular distance between the lines of action of a force and a point in space for moment calculations.

Keep in mind that resultant forces are the net result of the sum of all the forces present. Engineers like to do analysis using resultant forces since is greatly simplifies the modeling of the physical system.

While it is convenient to do stability calculations using the resultant forces of weight and buoyancy, it is sometimes necessary to use the distributed forces to do the engineering analysis. For example, if you want to study the bending tendencies of a ship's hull it is the distribution of weight over the length with respect to the distribution of buoyant force over the length that is important!

A vector is shown in a engineering diagram as an arrow. The arrow has a "head" at the pointing end and a "tail" at the extreme other end. The length of the arrow from the "tail" to the "head" should represent the magnitude of the vector. The direction that the arrow is pointing shows the direction of the vector. Exact placement of the vector is important in engineering. The point of application is shown by drawing a "dot". The arrow head may be placed on the dot (point of application) or the tail of the arrow may be placed on the dot. Either method is acceptable but sometimes one is preferred for clarity.

Students like to move vectors over a few tenths of an inch on the engineering diagrams they make because of some existing line that may be present on their diagram. Doing this is incorrect since it changes the real location of the vector. You must draw the vector wherever it falls regardless of the pre-existing drawing lines.

The arrow representing a vector should have the symbol naming the vector next to it with a half arrow over the symbol showing that it is a vector. (In textbooks the letter may be in bold print with no arrow or the arrow may be a full arrow due to the logistics of printing in the system that was used.) Typical symbols used to name a vector are English or Greek letters of the alphabet. The symbols often have subscripts to better clarify what it represents. For example:

$$\text{"}\vec{F}_B\text{"} \quad - \quad \text{represents the resultant buoyant force}$$

$$\text{"}\vec{\Delta}_S\text{"} \quad - \quad \text{represents the resultant weight of the ship.}$$

The magnitude of the resultant weight of the ship is called the "displacement" and has the same symbol but without the half arrow over it since displacement is a scalar. (Just like speed has the same symbol as velocity but speed would not have the half arrow over it since it is just the magnitude of velocity - a scalar.) Remember, the weight of a floating ship is the displacement.

Because the symbol for displacement in Naval Engineering is a capital Greek delta "Δ_S", Naval Engineers use a lower case Greek delta "δ" to represent a change in a property. Recall from your basic scientific knowledge a change in a property is always the final value minus the initial value.

For example, you will see symbols like this ("T" is used for draft).

"äT$_{PS}$"

This symbol is interpreted as, " the change in draft due to parallel sinkage - or the final draft minus the initial draft due to adding or subtracting weight from the center of flotation."

Understanding the underlying process or physics behind the notation used is a skill that is developed over time. When an engineer reads these symbols they "see" a paragraph of ideas. The symbols are a means of identifying and pointing to that knowledge piece. You have to force yourself into being trained this way.

NB: Remember when reading symbols to yourself always try to visualize the physical processes they are representing. When engineers reads an equation they do not see letters and numbers but they envision the physical principles the equation represents.

Think about the symbols you write and ask yourself could they be written differently for better clarity of the process. Keep in mind that engineering is about effective communication between other engineers, technicians, business people and even yourself in the future when you have forgotten the work you previously did!

1.6.2 Translation Versus Rotation

A ship freely floating in the water is subject to 6 degrees of freedom. (This is the same number of degrees of freedom that an airplane has!) Three are rotational, and three are translational. Rotational means spinning around the X, Y, or Z axes. Translational means moving in a straight line in the X, Y or Z directions. Shooting an arrow with a bow results in the translation of the arrow through the air.

For Naval Engineering the longitudinal axis of the ship (meaning from stern to bow or bow to stern) is always assigned as the X-axis. The elevation above or below the surface of the water or keel of the ship is always assigned as the Z-axis. The port to starboard or starboard to port direction is always assigned the Y-direction. The Y-direction can be called the transverse or arthwarthships direction.

For computational purposes it is convenient to place the origin of the X, Y, Z axis at the bow of the ship on the centerline level with the keel of the ship. In this way all X and Z values are positive. Both distances port of the centerline and angles of heel to the port are always assigned as negative. Distances to the starboard of the centerline and angles of heel to the starboard are always assigned as positive.

The location of an X, Y, Z axis is entirely arbitrary and mathematically it can be placed anywhere. Sometimes the origin is placed at midships, the longitudinal middle of the ship.

Sometimes the word "amidships" is used in place of midships. They both mean the same thing, the

longitudinal center of the ship.

A ship's motions are generally coupled rotational and translational motions that occur together. Often the motions are decoupled or separated for study purposes. Coupled means that you can't have one motion without the other and that the motions are dependent on one another. For example, when an ocean wave encounters a stationary ship it will cause the ship to pitch, heave, and roll. These motions are coupled and are inter-related. Special names are given for each of the rotational and translational motions as shown in Figure 1.1 .

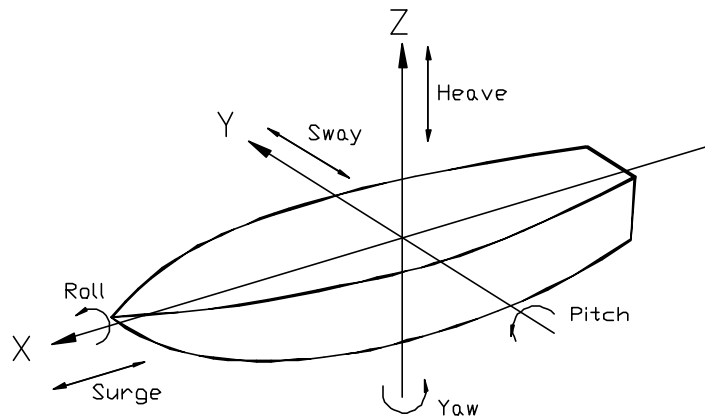In addition to these terms there are some other expressions used to describe certain ship motions.

Figure 1.1 - The 6 Degrees of Freedom of a Ship

! List the condition where the ship is in static equilibrium and down by the port or starboard side due to ship's center of gravity lying off the centerline. This condition is studied in Chapter 3.

! Heeling the condition where the ship is temporarily in static equilibrium and down by the port or starboard due to an external couple acting on the ship. In the case of heeling the resultant weight and buoyant force are not vertically aligned and will form a couple equal and opposite to the external couple acting on the ship.   This condition is studied in Chapter 4.

! Rolling the condition where a ship dynamically alternates between "down by the port" and "down by the starboard". The ship only passes through equilibrium points but is never in static equilibrium.

! Lolling the listing of the ship to small angles caused by the ship possessing a negative metacentric height. You will learn about metacentric height in chapter 3 and about lolling in chapter 4.

1.6.3   Force Versus Weight

When you know an object's mass and acceleration you can use Newton's second law to calculate the force exerted on the object. We will measure all forces in this class with the pound " lb",

from the "pound - slug" system. When an object is near the surface of the earth it will experience a gravitational force due to the acceleration of gravity acting on the objects mass. This force has a special name called the "weight" of the object. So weight is a force, a special force due to the acceleration of gravity near the earth's surface. For the calculation of an object's weight use Newton's second law with the acceleration of gravity as follows.

$$\vec{F} = \vec{W} = \frac{m\,\vec{g}}{g_c}$$

<div align="right">Equation 1-3</div>

The magnitude of the acceleration of gravity (g) varies with elevation and location but a commonly used number is 32.174 ft/s^2. For the units system used by Naval Engineers "g_c" is numerically equal to 1 so it is often left out of the equation.

You will need to be able to calculate weight given mass or mass given weight.

1.6.4   Moments Created by Forces

A moment is created by the action of a force applied at some distance from a reference point, such that the line of action of the force does not go through the reference point. Moments create the tendency for an object to rotate. The force acting on the object can also cause translation of the object.

When more than one force is acting on an object, the sum of the forces in the X, Y, and Z directions and the sum of the moments around the X, Y and Z axes will ultimately tell you if the object will translate and or rotate. If the sum of the forces and the sum of the moments add up to zero we say that the object is in "static equilibrium". Essentially this means it will be held in place with no tendency to rotate or translate.

NB: The two necessary and sufficient conditions for static equilibrium are...

$$\sum \vec{F} = 0 \qquad\qquad \sum \vec{M}_{origin\ p} = 0$$

<div align="right">Equation 1-4</div>

The reference point or origin chosen for the summation of forces or calculation of moments is arbitrary in the balancing process and is usually chosen out of convenience.   Once chosen, it may not be moved for all calculations thereafter.

A common example of an applied moment is when you take a wrench and turn a nut. The force is applied at the end of the wrench opposite the nut. The origin in this case is the nut. To loosen the nut on a threaded bolt you would turn it counter clockwise as viewed from the top view.

NB: The "right hand rule" - Take your right hand and make a "thumbs up" sign. Place your hand on a flat surface with your thumb pointing up and your fingers curling so that they are going in the counter clockwise direction as viewed from the top view. This is called the right hand rule and it defines how a "right handed thread" works. The direction of your thumb tells you that if you turn the nut in the direction your fingers are curled, the nut will go in the direction of your thumb.

For your purposes think of a calculation of a moment as the product of a distance multiplied by a force, where the distance is the perpendicular distance from the origin to the line of action of the force. When you think of a moment just remember the words, "distance times a force" or "lever arm and force" and it will serve you well. The units on a moment are units of a distance multiplied by units of force. In the "pound - slug" system these would be units of foot pounds (ft lb).

Ships will list and trim about a fulcrum called the center of flotation (F) . Adding, removing, and shifting weight on a ship can create a moment about the center of flotation. You will need to understand what a moment is to do list and trim calculations later on.

Some students confuse the word moment with momentum. They are not related at all. Momentum is the tendency of an object to keep moving and is numerically equal to the product of the object's mass and velocity.

1.6.5   Special Moments Called Couples

A couple is formed by a pair of equal, opposite, and parallel forces separated by a distance. A couple is considered a special moment because it causes pure rotation and no tendency to translate. Because of this property a couple is considered a "free vector" that can be placed anywhere on an object and still produce the same rotational effects. Since the couple is just a special moment it has the same units as the moment which are foot pounds (ft lb).

To numerically calculate the magnitude of a couple multiply the magnitude of the perpendicular distance between the parallel forces by the magnitude of one of the forces. You might ask, "which force do I use?" It doesn't matter since they are equal in magnitude. Students often want to multiply by the magnitude of both of the forces since both form the couple, but this is incorrect. To help you see why this is incorrect, think of choosing an origin for the calculation that is along the line of action of one of the forces. That force will not possess a lever arm, will not contribute to the rotational moment, and is not included in the calculation.

1.6.6   Hydrostatic Pressure

On the most fundamental level, pressure is the effect of molecules colliding. All fluids, which means liquids and gases, have molecules moving about each other in a random chaotic manner.

These molecules will collide and change direction exerting an impulse. The sum of all the impulses produces a distributed force over an area which we call pressure.

There are actually three kinds of pressure in fluid dynamics. They are static, dynamic, and total. The one described above is called static pressure. Dynamic pressure is the pressure measured in the face of a moving fluid. The total pressure is the sum of static and dynamic.

When the fluid is a liquid, we called the static pressure "hydrostatic pressure". Hydrostatic pressure is made up by distributed forces that act normal to the surface of the object in the water. It is possible to draw a simplified vector picture of these distributed forces which act over the surface of an object. It is important to note that the pressure always acts normal to the surface and it's magnitude is proportional to the depth of the water from the surface. The pressure can be resolved into components that act horizontal and vertical to the waters surface. All the horizontal components of pressure on a freely floating object will sum up to zero and cancel each other out. (Otherwise you could put an object in the water and it would move all by itself due to an unbalanced horizontal force.) Only the vertical component of the distributed force will be left.

The sum of all the distributed vertical forces is called the resultant buoyant force (F_B). If a ship is freely floating in the water, the resultant buoyant force on the ship must be equal in magnitude to the weight of the ship or else the ship would sink or fly!

A resultant force is the vector sum of all the individual forces. Engineers prefer to do analysis using resultant forces because it greatly simplifies the modeling of the physical system.

While it is convenient to do stability calculations using the resultant forces of weight and buoyancy, it is sometimes necessary to used the distributed forces to do the engineering analysis. For example, if you want to study the bending tendencies of a ship's hull it is the distribution of weight over the length with respect to the distribution of buoyant force over the length that is important!

1.6.7   Linear Interpolation

You are often faced with having to find the value of some parameter in a table as a function of something you know. For example, you will be asked to find the distance from the keel to the ship's transverse metacenter (KM_T) in the ship's "Tabular Curves of Form". The independent variable you will know will be either the mean draft (T_m) or displacement ($\ddot{A}_S$) of the ship. If you don't find your exact numerical value of mean draft or displacement you will have to interpolate a value between those in the table. The most common assumption made in interpolation is to assume that the parameters vary in a linear fashion between the parameters listed. This means that you can approximate the curve between values in the table with a straight line. This is called, "linear interpolation". Most of you have done this many times but won't remember how to do it or what it really means.

To find the missing interpolated value set up a table with all your values you know in it. Then make a ratio of differences and solve for the unknown value.

For example, find the distance from the keel to the transverse metacenter using the following partial tabular curves of form for an FFG-7 for a mean draft of 10.35 feet. (It's not important for you to understand this quantity, you will soon!)

Given:

FFG-7 Tabular Curves of Form Hydrostatic Properties No Trim, No Heel, VCG = 0.00 All distances in feet as measured from Keel, Centerline, or Midships		
Mean Draft (T_m) (ft)	Displacement ($\ddot{A}_S$) (LT)	Transverse Distance From Keel to Metacenter (KM_T) (ft)
10.00	1838	23.64
11.00	2156	23.48

Solution:

T_m	KM_T
10	23.64
10.35	Unknown Value
11	23.48

$$\frac{T(10.35\ ft)\ \&\ T(10\ ft)}{T(11\ ft)\ \&\ T(10\ ft)}\ ,\quad \frac{KM_T(10.35\ ft)\ \&\ KM_T(10\ ft)}{KM_T(11\ ft)\ \&\ KM_T(10\ ft)}$$

$$\frac{10.35\ ft\ \&\ 10\ ft}{11\ ft\ \&\ 10\ ft}\ ,\quad \frac{KM_T(10.35\ ft)\ \&\ 23.64\ ft}{23.48\ ft\ \&\ 23.64\ ft}$$

$$KM_T(10.35\ ft)\ '\ 23.58\ Ft$$

When doing this calculation on labs or homework you must show the generalized equation and substitution of values so that another engineer can check you work easily. Always check your final answer and make sure it is between the other values in the table.

In general, whenever doing a calculation in this class always show the generalized equation, the substitution of all numbers, and finally the numerical answer. You are attempting to communicate your work to someone else to check and therefore you must show all logical steps that led you to the conclusions reached. A correct numerical answer without the supporting work is useless to an engineer. This class is not about finding "a number"!

1.6.8   Mathematical Moments

In science and math the following integrals come up fairly often in the mathematical descriptions of physical processes.

$$\int_m s\ dm$$

$$\int_m s^2\ dm \qquad\qquad\qquad \text{Equation 1-6}$$

$$\int_m s^3\ dm$$

Where "s" typically represents a distance and dm is any differential property "m". Because they are so familiar across many disciplines of science and mathematics they are given special names called respectively, first moment, second moment, third moment etc. The order of moment is the same as the power on "s".

There is no one generic physical meaning to these moments. The meaning is dependent on which discipline of science it was derived from. When "s" is a distance, a direction with respect to an axes must be given. When moving in the "x" direction the moment is said to be with respect to the Y-axis. When moving in the "y" direction the moment is said to be with respect to the X-axis. Common properties of "m" for Naval Engineering are length, area, volume, mass, and force. The units on the first, second or any N'th moment are easily figured out. The "s" is a distance so that you will obtain the units of feet to the N'th power. The property "m" will have its own obvious units to multiply the feet to the N'th power by.

Here are some common examples of mathematical moments. Notice the word translations and the units moment would have.

Example 1:

$$\int_m x\ dm \hspace{4cm} \text{Equation 1-7}$$

Assuming "m" is for mass, this is the first moment of mass in the x-direction or with respect to the Y-axis. The units would be ft multiplied by slugs or ft-slugs.

Example 2:

$$\int_m y\ dV \hspace{4cm} \text{Equation 1-8}$$

Assuming "V" is volume, this is the first moment of volume in the y-direction with respect to the X-axis. The units would be ft multiplied by ft^3 or ft^4 .

Example 3:

$$\int_m y^2\ dA \hspace{4cm} \text{Equation 1-9}$$

Assuming "A" is area, this is the second moment of area in the y-direction or with respect to the X-axis. The units would be ft^2 multiplied by ft^2 or ft^4 . Recall for Naval Architecture "Y" is used as the transverse direction exclusively.

NB: When mass is used instead of area, it is called, "the second moment of inertia", or more commonly "the moment of inertia". The units would be ft^2 multiplied by slugs or ft^2-slugs. Many of you have probably heard of the moment of inertia!

Example 4:

$$I_T \ ' \ \int_m y^2 \ dA \qquad\qquad\qquad \text{Equation 1-10}$$

For Naval Engineering this is called the second moment of area in the transverse direction instead of second moment of area in the y-direction. (This is used in metacentric radius and free surface calculations later in this book.)

Hopefully, this will have de-mystified some of the confusion about mathematical moments so that it will make your study of them easier. Remember it is basically a math concept that only takes on meaning once it is applied to a specific area of study.

1.6.9   The Concept of Weighted Averages

One of the most useful concepts in engineering is the concept of a weighted average. Like any average it will give you a number bigger than the smallest and smaller than the biggest. The weighted average will fall somewhere between the extremes based on the weighting factor used.

To find the weighted average of any variable "X", take the variable your averaging and multiply it by the weighting factor for that value of "X". Do this for all values and then sum up. In calculus form this translates to the following equation.

$$The \ Average \ of \ Variable \ "X" \ ' \ \int_{all \ X} (A \ Value \ of \ X) \ (It's \ Weighting \ Factor)$$

$$- \sum_{all \ X} (A \ Value \ of \ X) \ (It's \ Weighting \ Factor) \qquad \text{Eqn 1-11}$$

$$- \sum_{all \ X} (A \ Value \ of \ X) \left(\frac{A \ Small \ Piece}{The \ Total} \right)$$

The weighting factor is a fraction that weights the value of "X" appropriately to declare the contribution "X" should make in the average. The weighting factor is usually constructed by thinking about putting a small piece over the total. The weighting factors can be ratios of pure numbers, areas, volumes, lengths, masses, forces, fluxes or anything. It all depends on how you want to weight your average!

As a simple example you could find the average on a test by using this method. Suppose 5 students received an 80% and 10 received a 90% and 5 more received a 100%. The average could be found by:

$$\textit{Average Test Score } {}' \sum \textit{(Test Score) (Weighting Factor for each Scrore)}$$

$$\textit{Average Test Score } {}' \ 80\% \left(\frac{5}{20}\right) \% \ 90\% \left(\frac{10}{20}\right) \% \ 100\% \left(\frac{5}{20}\right)$$

$$\textit{Average Test Score } {}' \ 90\%$$

You can use this concept in the future to find the Longitudinal Center of Flotation by finding the average "x-distance" weighted by area, the Longitudinal Center of Buoyancy by finding the average "x-distance weighted by the volume, the new Vertical Center of Buoyancy (VCB or KG) after a weight shift by finding the average KG distance weighted by a weight ratio.

1.6.10 Bernoulli's Equation

It is useful to have a short discussion of externally flowing water around surfaces. This is the situation that occurs when water flows around a ship's rudder, submarines planes, or the hull of any vessel moving through the water. Typically, we model the flow as if it occurred in streamlines such that the water molecules were lined up following each other in layers downstream. This streamline layered flow is referred to as laminar flow.

If the flow is incompressible it means that the density is not changing anywhere along the flow and there is no contraction or dilation of the water molecules. If the water molecules are not rotating it is called irrotational flow and the fluid is said to have a vorticity of zero. If there are no shearing stress between layers of the flow the fluid is said to be inviscid. If the flow is steady it means that at any one location along a streamline the properties of the fluid are not changing with time (although the properties can change from location to location).

For steady incompressible inviscid flow the sum of the flow work plus the kinetic energy plus the potential energy is a constant along a streamline. This is Bernoulli's Equation and it can be applied at two different locations along a streamline to yield the following equation

$$\frac{p_1}{\tilde{n}} \% \frac{V_1^2}{2} \% g \ z_1 \ {}' \ \frac{p_2}{\tilde{n}} \% \frac{V_2^2}{2} \% g \ z_2 \qquad\qquad \text{Equation 1-12}$$

Where "p" is the hydrostatic pressure, "V" is the speed of the water, "g" is the acceleration of gravity, "z" is the height about some reference datum, and "ñ" is the density of the water.

The first term "p/ñ" is called the flow work, the second term "$V^2/2$" is called the kinetic energy term, and the third term "g z" is called the potential energy term.

This equation is often used to explain why lift is generated over rudders, planes, and blades on a propeller.

Many people confuse Bernoulli's Equation with the steady flow energy equation for fluids. Although they are very similar in format, the energy equation is much less restrictive in it's usage and it can include terms for heat added or removed, work done by or on the fluid, and include a term that accounts for the energy losses due to friction (sometimes called a head loss term). The Bernoulli equation stems from a linear momentum concept, whereas the energy equation stems from an energy concept.

1.7 Conclusion

You now have a sufficient basis on which to start your study of Naval Engineering Principles.

Please re-read this chapter after you have completed a couple of weeks of class. You will then have a better understanding of the fundamental principles of engineering and how they apply to your EN200 course.

HOMEWORK - CHAPTER ONE

Get into the habit of doing your homework correctly, in particular.

> **!**   Your homework must be your own work.
>
> **!**   You must finish before entering class. If you had problems with the questions, any work you did in class must be clearly represented.
>
> **!**   Do not blindly copy out of the text. Put answers in your own words. Close your notes and try to answer the questions! Information is supposed to pass through your head before going down on the paper.

1.   a.   Sketch the velocity of a Yard Patrol Craft (YP) moving from zero ft/s to its top speed of 20 ft/s. Time to reach maximum speed is 26 seconds. Use velocity as the dependant variable and time as the independent variable.

   b.   Give the calculus equation that represents the area under the sketched curve between zero and 10 seconds. What does this area physically represent?

   c.   How would you calculate the acceleration of the YP at t = 5 seconds?

2.   What does the area under a "ship's sectional area" versus "longitudinal distance" curve physically represent? State the units of each axis and the area under the curve.

3.   Which system of units are used in Naval Engineering I (EN200)? State the units in this system for the following parameters:

   force   mass   volume   time   density

   a moment   a couple   pressure   the second moment of area.

4.   Sketch a diagram showing the six degrees of freedom of a floating ship. Name each one on your diagram using the correct Naval Engineering terminology.

5.   What are the necessary and sufficient conditions for static equilibrium?

6.   A ship heeling to starboard due to an external moment can be represented by the following diagram. Use the given quantities to calculate the magnitude of the internal couple which is being generated.
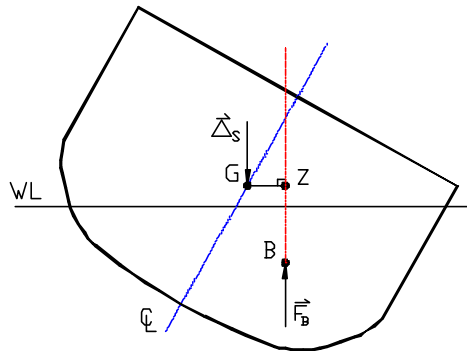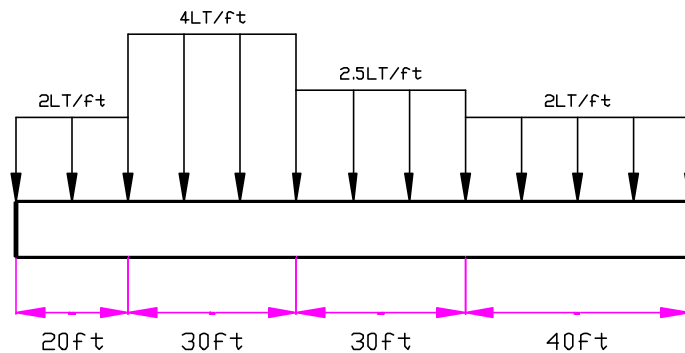
$\ddot{A}_S = 2000$ LT

$F_B = 2000$ LT

The distance between G and Z (GZ) = 1.5 ft

7.   The following diagram represents the distributed weight of a small ship.

    a.   What is the difference between a distributed force and a resultant force?

    b.   Calculate the resultant force of the ship. The concept of weighted averages may be useful.

4LT/ft

2.5LT/ft

2LT/ft

2LT/ft

20ft   30ft   30ft   40ft

25 ft/s

8.   The diagram to the right shows the flow velocities past a submerged hydrofoil connected to an advanced marine vehicle. Use Bernoulli's Theorem to explain the forces being experienced by the hydrofoil.

19 ft/s